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Physeal Bar Resection For
Partial Growth Plate Arrest

Hayden Ronald Hobbs

HBBHAY001

Physeal Bar Resection For Partial Growth Plate Arrest

By

Hayden Ronald Hobbs

HBBHAY001

Submitted to the University of Cape Town

In fulfillment of the requirements for the degree

Master of Medicine in Orthopaedics

Faculty of Health Sciences

University of Cape Town

Supervisor: Professor EB Hoffman

Consultant and Head of Paediatric Orthopaedics

Red Cross Hospital and Maitland Cottage Hospital

University of Cape Town

Submitted: August 2009

Based on a study performed at Maitland Cottage and Red Cross Memorial Hospitals

Presented at the South African Orthopaedic Association congress in Durban

September 2006

Published in the South African Orthopaedic Journal Summer 2007 (vol 6 No 1)

DECLARATION

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Abstract

The results of 21 physeal bar resections for growth plate arrest performed over a 17 year period (1987-2003) were assessed retrospectively.

Five (24%) of the growth plates failed to resume growth. The remaining 16 were followed up for 2 to 8 years (11 to maturity). Eight (38%) growth plates (6 to maturity) had an excellent result and growth exceeded the expected normal. Eight (38%) growth plates (5 to maturity) had a good result and resumed normal growth.

All five failures occurred in patients with the commonest aetiologies i.e. distal femoral physeal fractures (3 of 5) and meningococcal septicaemia (2 of 5).

We concluded that physeal bar resection was a worthwhile procedure if the size of the bar was $\leq 30\%$. In growth plate arrest due to distal femoral physeal fractures and meningococcal septicaemia, the prognosis, however, is guarded.

Introduction

Partial growth plate arrest of an epiphyseal growth plate (physis) is usually the result of a bony bar that forms between the epiphysis and the metaphysis. In the presence of substantial remaining skeletal growth, this can lead to a limb length discrepancy, progressive or recurrent angular deformity and joint distortion (figure 1). The size and location of the physeal arrest and the amount of skeletal growth remaining determine the clinical deformity that eventually develops. Complete growth arrest will produce limb length discrepancy without any angular deformity. It is due to this that partial growth plate arrest is often a more serious and difficult problem to treat than complete arrest.



Figure 1 :

A physeal bar causing angular deformity and joint distortion

Injury to the growth plate can result in physeal arrest. This most commonly occurs due to trauma, such as in a growth plate fracture, but may also occur due to causes such as infection, radiation, burns (thermal and electric), tumours and iatrogenic insults. Vascular abnormalities that result in decreased vascular supply to the germinal cells of the physis may also result in bar formation.^{1,2} Vascular causes include vasculitis and thrombo-embolism from meningococcal septicaemia, localized vascular occlusion or trauma and altered blood flow from tight dressings or plaster casts.

The most common cause of physeal arrest is post traumatic and bony bars can occur after any type of growth plate fracture, classified by Salter-Harris.³ Although type II Salter-Harris injuries are the most common, type IV Salter-Harris injuries however have the greatest potential to form a bar due to the fact that the fracture crosses the epiphysis, physis and metaphysis. These tend to be linear bars. Type V injuries produce complete growth plate arrest and not partial.²

It is important, therefore, to follow up growth plate fractures and monitor them for the formation of a physeal bar. Harris lines or growth disturbance lines^{6,7} may be used to detect any partial growth arrest. These lines are easily evident on standard radiographs. Growth disturbance lines are associated with episodes of illness or injury during childhood. They are dense sclerotic lines from an increased trabecular bone thickness due to the insult to the physis, and as physis growth continues, the physis grows away from the sclerotic line. After a fracture, the sclerotic line usually appears after 6 to 12 weeks, and extends across the whole width of the metaphysis. It is then unlikely that a physeal bar has formed and the physis will continue to grow away from the sclerotic line in a linear, parallel direction (figure 2). If the sclerotic line however has any focal defects in it, it is likely that there may be growth impairment. The sclerotic line then grows away from the physis in a non parallel fashion (figure 3).⁷



Figure 2: Harris line
parallel to growth plate



Figure 3: Harris line
incomplete and not parallel to
growth plate

The treatment of these growth plate injuries can also produce a bony bar by the placement of metalware across the physis. Many factors are involved in this, most importantly the size of the pin crossing the physis and whether the pin is smooth or threaded.⁴ Threaded pins and the larger the pin, more commonly result in a bony bar. In an animal study done by Mäkelä et al⁵, they found that if less than 7% of the total area of physis is damaged, permanent growth disturbance usually does not occur.

Another factor that influences physeal bar formation is the anatomic difference between the various physes. Important factors involved are the size of the physis, the amount of growth that occurs at the physis and the anatomical contour of the physis (i.e., whether the physis lies on one plane or is irregular and lies in many planes). Although the distal femoral physis and proximal tibial physis are infrequently injured (they account for about 3% of all physeal injuries), they account for the majority of bony bar formations.^{8,9,10} Both these physes have a large surface area and undergo a significant amount of growth. They are also both fairly irregular. This is in stark contrast to the distal radius physis which accounts for the most growth plate fractures but is a very uncommon site for bony bar formation.^{8,9,10}

Evaluation

An initial thorough history and examination are crucial in the diagnosis of a partial growth plate arrest. Partial growth plate arrest may be diagnosed clinically initially because of the limb length discrepancy and angular deformity that it can produce. However, it is usually picked on follow up for a growth plate injury. Routine roentgenograms of the involved limb may pick up angular deformity and localize the physal bar. It is at this stage that Harris lines or growth disturbance lines can be useful and should be actively looked at.

Four major factors must then be evaluated and taken into account. These are: (1) the amount of growth remaining; (2) the location of the lesion; (3) the extent of the physal bar and (4) the aetiology of the physal bar.

The amount of growth remaining is determined by physiologic or bone age. This is done by the comparison of an anteroposterior radiograph of the left hand with an atlas devised by Greulich and Pyle¹¹, which gives the skeletal age to the nearest six months. Bar resection is usually only considered when more than two years of skeletal growth remains.

The location and size of the bony bar can then be further assessed via plain radiography, multiplanar tomography, Computerized Tomography (CT) scan or Magnetic Resonance Imaging (MRI). Plain radiography is initially important to evaluate the physis involved and the amount of angular deformity. Plain radiography can also be used to determine the lengths of the involved and uninvolved extremities for comparison. The three methods commonly used for this are teleroentgenography, X-ray scanography and orthoroentgenography.

Multiplanar tomography can be used to determine the location of the bar and area of involvement of the bar. Anteroposterior and lateral tomograms should be obtained with cuts less than 3mm preferably. The cuts however need to be perpendicular to the plane of the physis, otherwise the bony bar may be missed. Other disadvantages of tomograms are that they do not differentiate between fibrous tissue and cartilage and

they have more radiation exposure than computed tomography and conventional radiography. In addition, they are very labour intensive and time consuming. These tomograms are then used to construct a map of the physal bar to represent the cross sectional area of the physis. This mapping technique was described by Carlson and Wenger¹² and is used to indicate more graphically the location and size of the bar. (figure 4)

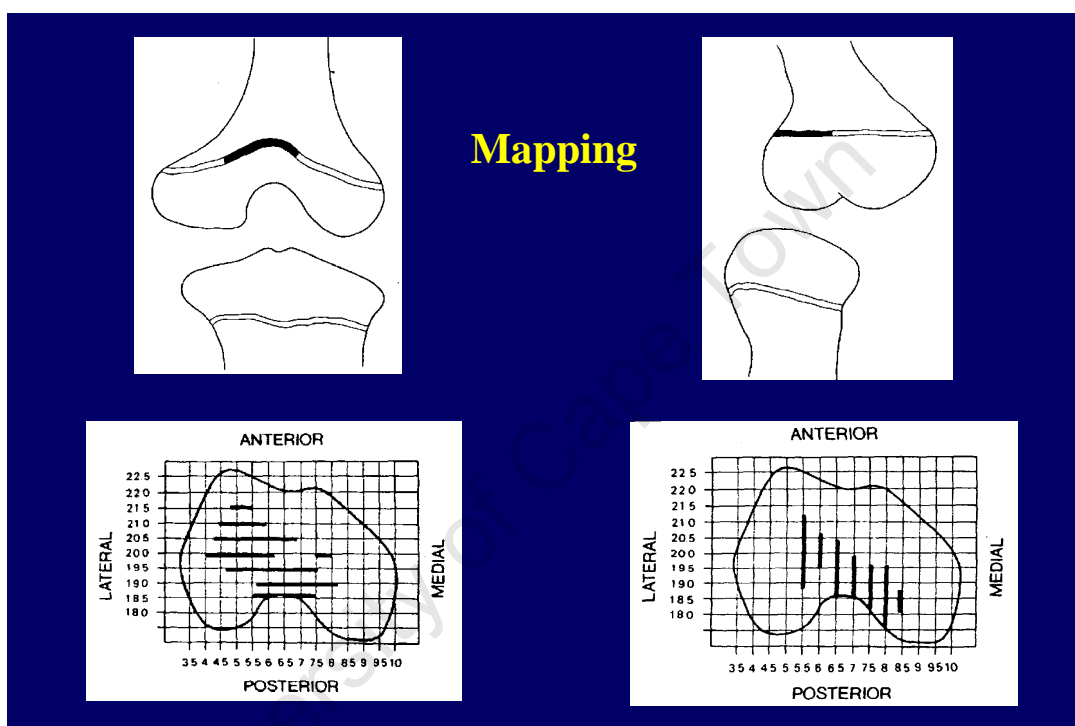


Figure 4:

The mapping technique as per Carlson and Wenger (1984)¹²

Computed Tomography may also be used to evaluate the bar and is a good modality for bar localization. There has been varying degrees of enthusiasm for its use.¹³ Axial CT scans with the cuts being parallel to the involved physis are extremely difficult to obtain with the marked deformity that may occur in the physes affected by a bar. Sagittal and coronal cuts perpendicular to the physis are therefore used and provide the same information as tomograms. CT scans however cost more,

expose the patient to more radiation and take longer than conventional radiography and are therefore unfavoured by many authors.¹⁴⁻¹⁶

More commonly preferred is magnetic resonance imaging (MRI). Sagittal and coronal planes are used and because the image is reconstituted, the patient does not need to be positioned in a specific manner within the MRI machine (i.e. the physis does not need to be perpendicular to the plane of the MRI). MRI may therefore be useful especially in those growth plates which have an undulating nature and the plane of the physis is irregular (i.e. the distal femoral and proximal tibial physes). Three dimensional (3D) reconstructions of the physis may also be obtained and used to map out the physal bar.¹⁵ One is also able to distinguish whether the bar is bony, fibrous or cartilaginous.¹⁶ Smaller areas of involvement may also be detected easier and earlier. These smaller areas may be missed on routine Xrays. (figure 5)



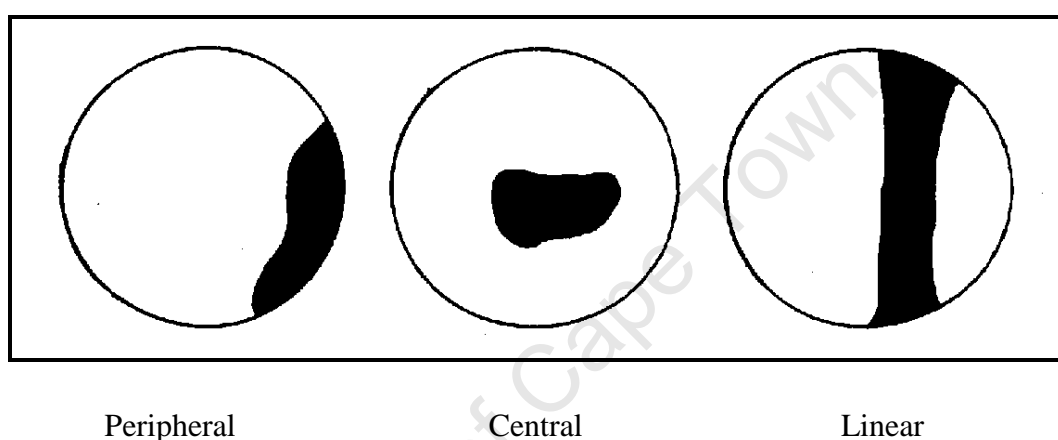
Figure 5:

Xray of patient with meningococcaemia showing a large proximal tibial physis bar (almost complete). The MRI however also picked up a smaller bar in the distal femoral physis unseen on the Xray

Classification

Once physeal bars have been identified and defined, they can then be classified according to the pattern of growth plate arrest. Three patterns of partial plate arrest have been identified and depend on the location of the physeal bar (picture 6).

Figure 6: Classification



The most common is a peripheral bar, which produces mainly an angular deformity. The next type is a central bar, which causes a central tethering of the growth plate resulting in cupping of the physis (picture 7) and mainly a limb length discrepancy with a deformed physis. This last type is a linear bar and is usually the result of a Salter Harris IV fracture. It may involve portions of the central or peripheral physis.



Figure 7:

Central bar causing cupping of the physis

Treatment

There are many options to treat physeal bars, which are dependant on three factors; namely the location of the bar, the size of the bar and the amount of growth remaining.

Treatment strategies include:

1. A shoe raise when the expected leg length discrepancy (LLD) is anticipated to be less than 2 cm at maturity with no angular deformity.
2. Epiphysiodesis (arrest of the remaining injured physis) in an older child when angular deformity is beginning to occur and the leg length discrepancy will be of little functional consequence (less than 2 cm).
3. Contralateral epiphysiodesis of the same or adjacent physes in the uninjured limb, when the resulting limb length discrepancy would be greater than 2 cm but less than 5 cm.
4. Lengthening of the injured limb (or shortening of the uninjured limb) when the resulting limb length discrepancy would be greater than 5 cm. This is usually combined with an epiphysiodesis of the injured physis.
5. Angular correction via a traditional closing- or opening-wedge osteotomy, or more commonly a barrel vault or chevron osteotomy. This can be done with an epiphysiodesis or as an isolated procedure. If done without an epiphysiodesis, angular deformity may reoccur and a repeat osteotomy may be necessary.
6. Physeal distraction with or without physeal bar resection can be attempted. This can be done for small bars and generally breaks the bony bar but the procedure usually leads to complete arrest and closure of the physis.^{17,18}
7. Physeal bar resection in order to reestablish growth of the physis. This may be combined with an osteotomy if angular deformity exists. In this situation with excision of the physeal bar, angular correction is often unnecessary if the angular deformity is less than 20 degrees. This is may be indicated when less than 50% of the physis is damaged, and more than 2 years of growth remains in the injured physis.
8. Combinations of the above procedures.

In general, arm length discrepancies present very little problem and discrepancies of up to 6 cm or less are best left untreated. Angular deformities in the upper limb however need to be addressed. Fortunately physeal bars in the upper limbs are very rare.

In the lower limb however, leg length discrepancies are of clinical significance and need to be treated.

- A leg length discrepancy of less than 2 cm is generally treated with a shoe raise or may be left untreated.
- A leg length discrepancy of 2 to 5 cm may be managed with a contralateral epiphysiodesis if sufficient growth remains to correct the discrepancy.
- Leg length discrepancies of greater than 5 cm may be treated with lengthening of the involved bone or shortening of the uninvolved limb with all the subsequent morbidity that accompanies that procedure.

Physeal bar excision is an option, especially when the expected or resulting leg length discrepancy will be more than 2 cm or when it is causing an angular deformity. When successful, excision of the physeal bar avoids the potential morbidity of the other procedures, especially lengthening procedures. If it is however unsuccessful, it does not compromise the use of the other procedures and they may still be used.

Excision of Physeal Bars

History

The excision of physeal bars has been described and the technique, on which it is based, has a firm experimental basis described by Österman¹⁹ and Langenskiöld.²⁰ Initial experiments were conducted on animals in an attempt to prevent the formation of a physeal bar.^{1,4,21,22} Although the experiments had variable results, there was enough success to suggest that physeal bars could be prevented. It was discovered though, that if interposition material was not inserted into the defect of the physis (where it was injured), a bar consistently occurred.

Animal experiments were conducted to discover if a physeal bar could be resected and if growth resumed.^{19,21} The results were yet again variable but it was reaffirmed that when interposition material is not inserted into the defect of the resected physeal bar, the bar reoccurred.

Langenskiöld pioneered the first excision of a physeal bar in humans in 1967.²³ Langenskiöld (1967, 1975)^{23,24} and Österman (1972)¹⁹ first described the principles of growth plate arrest and resection. They showed that following a growth plate injury, the formation of a physeal bar between the epiphysis and metaphysis can be prevented by the insertion of interposition material. They also showed that once a bony bar already exists, it can be excised and replaced with interposition material, and the destroyed portion of the physis is gradually replaced by regeneration from adjacent parts of the physeal plate. Österman also showed that when a physeal bar is resected and replaced with interposition material, recurrence of the bony bar is usually prevented and that gradual correction of the angular deformity by growth may take place.

Interposition Material

Many different types of interposition material have been used over the years. Fat (local or harvested from another site, usually the buttock), cartilage, silicon and cranioplast have all been used.^{9,25,26} In a search for an interposition material to prevent scar formation in scoliosis surgery, Langenskiöld and Michelsson 1960 discovered that autologous fat was suitable for this purpose. Fat and cartilage was therefore initially used. Fat has the advantage of being autologous and can be obtained from the incision along the periphery of the wound. Some authors however prefer harvesting fat from a different site, usually the buttock.²² Fat has the disadvantage of lacking haemostasis in the resected cavity and tends to float out of the cavity, especially when the tourniquet is released. The other problem with fat interposition is that it weakens the bone, and therefore weight bearing bones need to be protected on the post-operative period. Fat also tends to stick to the physis and grows with the epiphysis.^{22,27}

Cranioplast is another commonly used material. Cranioplast is methyl methacrylate without the Barium, which is advantageous as it is radiolucent and therefore complete excision of the bony bar and reformation of the bar is easier to identify. It also provides excellent haemostasis and does not weaken the bone as fat interposition does. Cranioplast is formed by adding a monomer (liquid) to a polymer (powder) and is easily moulded to fill the resected cavity completely. It may be poured into the cavity, especially if large, whilst still in its liquid state. When inserting the cranioplast, due to the fact that it is an inert material, it does not stick to the physis and may need to be pinned to the epiphyseal cavity. This is done so that with growth, the cranioplast moves with the epiphysis and presumably continues to protect the physis from reformation of the bar.

Silicone rubber may also be used and is also an inert material and behaves in the same way as cranioplast. It can be moulded and pressed into the resected cavity.

Technique of Resection

For all types of bars, the surgical goals are to; 1) completely remove the bony bar bridging the physis whilst preserving the remaining healthy physis; 2) fill the cavity with interposition material to prevent reformation of the bony bar and 3) to correct any angular deformity by concomitant osteotomy as necessary.²⁷⁻³¹

Each type of bar is approach on an individual basis and a knowledge of the surgical anatomy is important in this respect.³⁰

Central bars are approached from the metaphysis, either by raising a metaphyseal cortical window or via an osteotomy. Surgical preference and the possible need for a concomitant osteotomy dictate which option is selected. It is important not to approach the bar via the periphery and the perichondral ring should be kept intact. A peripheral bar can be approached directly from the periphery, with excision of the overlying periosteum. A corrective osteotomy may be needed in addition, as it is the peripheral bars that usually cause the angular deformity. Linear bars require careful evaluation and the approach to them must be individualized. It is important to ensure that the whole bar is removed and linear bars may extend completely across the physis.

With all the types of bars, the normal physis is defined at the periphery of the bar. The bar itself is a hard sclerotic area of bone or fibrous tissue in the midst of cartilage (figure 8). The bar is then removed using a burr, gouge or osteotome (figure 9). It is important to remove the bony bar back until normal physis is visible circumferentially in the cavity created (figure 10). An effort should also be made to remove as little normal physis as possible. It is therefore important to have a good light source to aid in the ability to see the normal physis. Some surgeons also use magnification, via loupes or an operating microscope, and fluoroscopy.^{9,29,31} The contour of the cavity is also important as one would like the interposition material to remain in the epiphysis. Bar reformation is less likely when the interposition material remains in the epiphysis.²⁹ The cavity is therefore enlarged into the epiphysis trying to create a collar button effect.

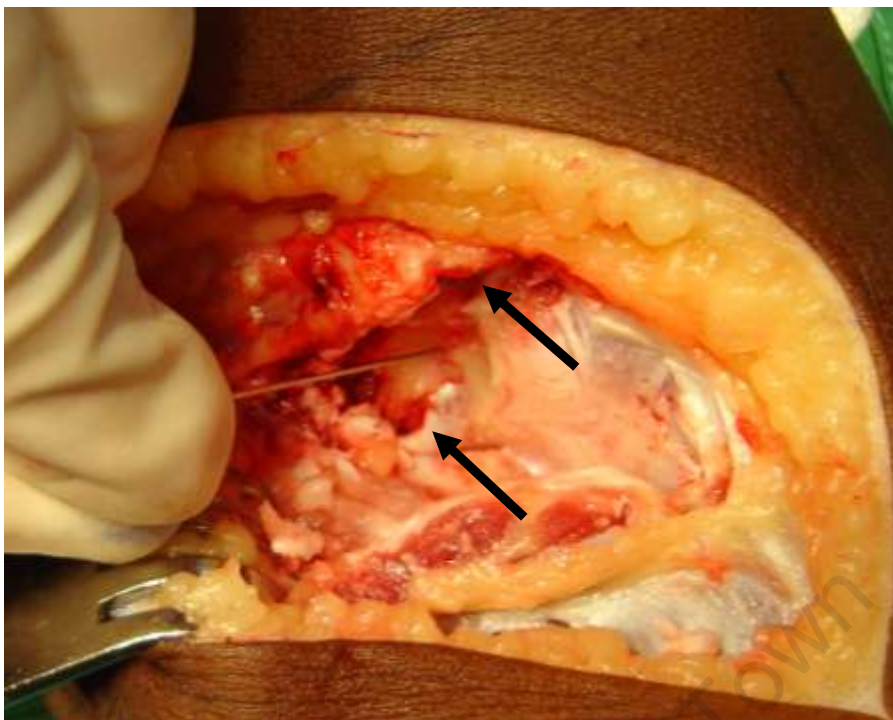


Figure 8 showing a hard sclerotic bony bar (needle in the bar). The dark arrows are pointing to the normal physis on either side of the physeal bar.

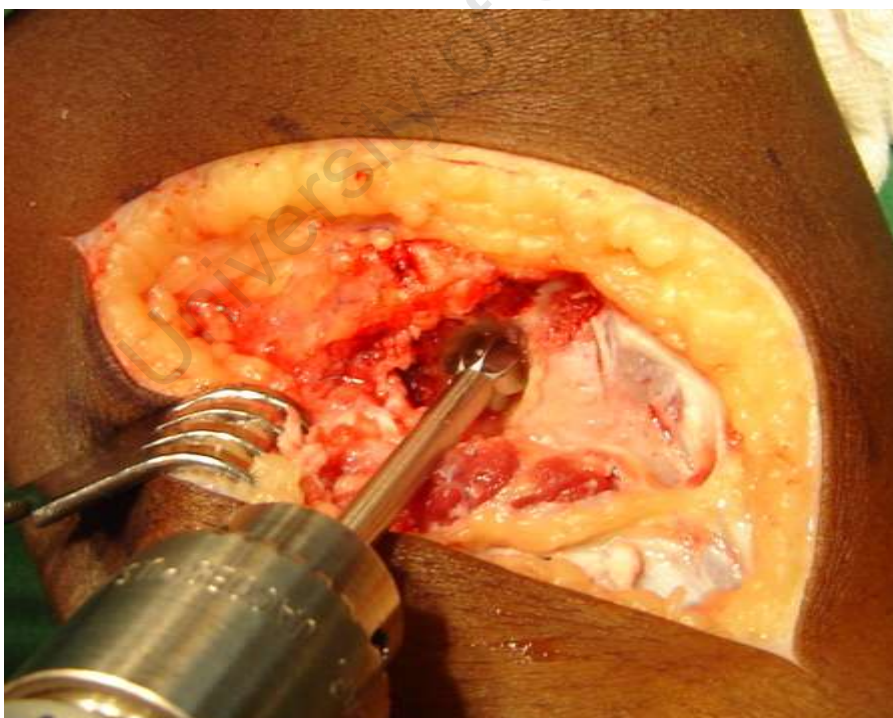


Figure 9: using a burr to remove the physeal bar

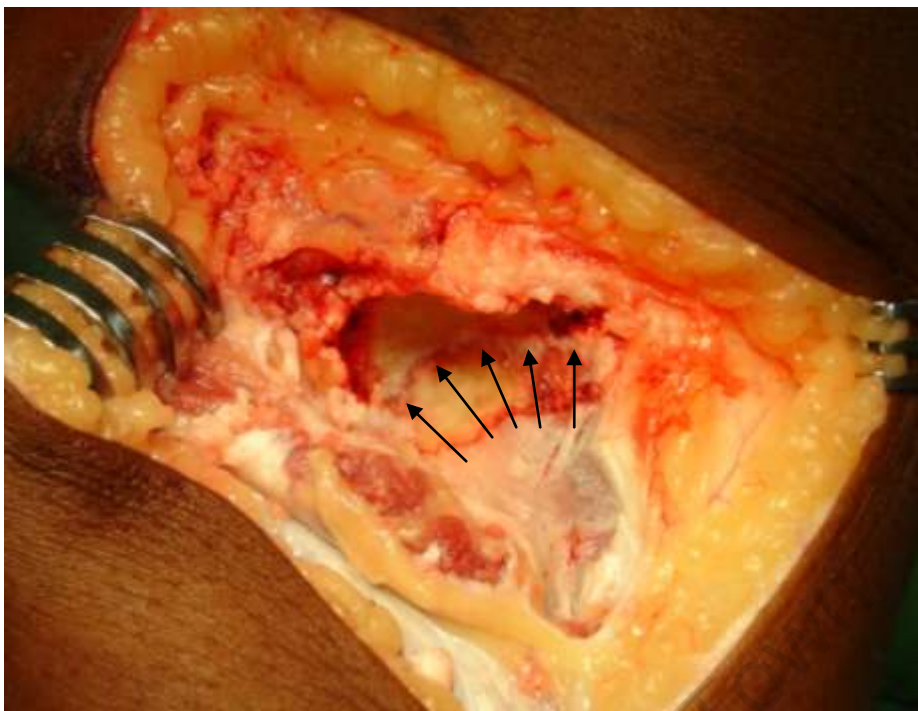


Figure 10 showing normal physis visible circumferentially in the cavity where the bar was removed

The defect is then filled with an interposition material of the surgeon's preference as described earlier. The interposition material is moulded and contoured into the cavity as a collar button (picture 11). The interposition material may also be pinned in situ to the epiphysis using Kirschner wires.

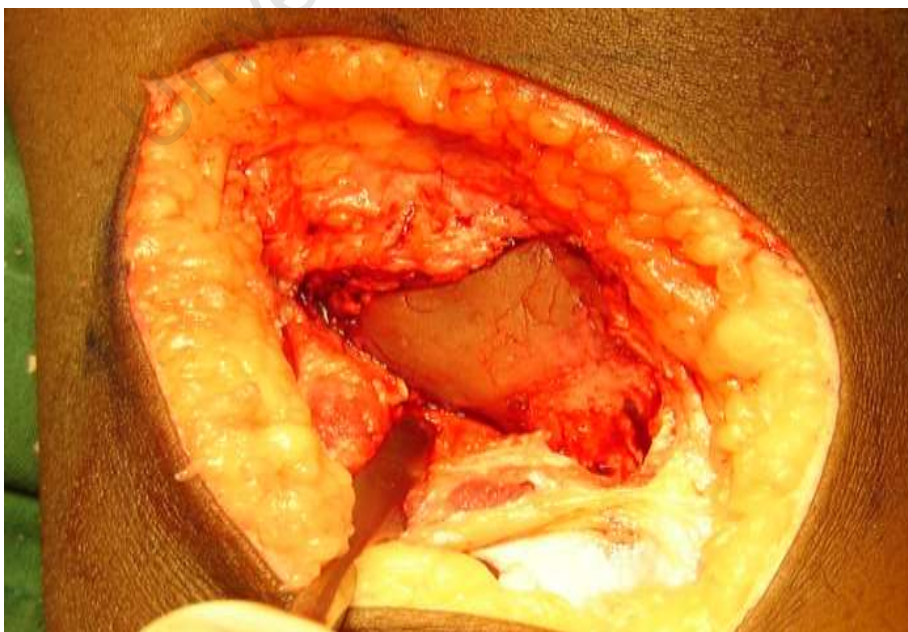


Figure 11: Cranioplast moulded into the defect

Parallel Kirschner wires are then inserted as metal markers into the metaphysis and epiphysis (figure 12). The markers should not be in contact with the interposition material and should be in the same plane as the physis. These metal markers serve as reference points in order to record and calculate the amount of linear and angular growth that may occur post operatively.



Figure 12:

Parallel K-wires inserted into the epiphysis and metaphysis

Angular deformity tends to correct spontaneously once the deforming force has been removed and growth resumes. If the angular deformity is however greater than 20 degrees, a concomitant osteotomy should be done at this stage.²⁹

Post Operative Management

If cranioplast has been used as the interposition material and no concomitant osteotomy has been performed, the patient may fully weight bear and no protection is necessary, and may begin movement of the adjacent joint when pain allows. If fat or a concomitant osteotomy has been performed, the patient should be protected in cast until union or healing has occurred (usually about 6 weeks).

The patient should be followed up to maturity. Initially the patient is followed up to see how much growth occurs. Routine X-rays are taken post operatively and then comparative X-rays are taken thereafter in order to measure the amount of growth that occurs (i.e. the distance between the two metal markers). Angular correction is also observed.

It is important to note that even though growth may occur initially, it sometimes stops abruptly with reformation of the physal bar at a later stage. This occurs classically in physal bars caused by meningococcal septicaemia.

Results

Initial reports of the results of growth plate resection were viewed with enthusiasm and great expectation. The first reports showed good results (where growth resumed in the affected limb). Langenskiöld (1981)⁹ used fat as the interposition material and had good results of 84% of the 43 physeal bars excised in 35 patients (5 were recurrent bars). Seven of the resected bars failed to resume growth. He also showed that resection of the physeal bar prevents joint surface deformation. This can not be achieved when performing a limb lengthening or osteotomy of the affected limb.

Bright (1982)²⁵ using silicone rubber as an interposition material reported good results in 100 patients treated in their series.

These results were confirmed by Petersen (1990)²⁹, who using mainly cranioplast (110 cases), reported 83% good results in 114 excised physeal bars. He also showed that the treated limb often grows faster than normal limb and catches up growth. This may be due to the physis at the opposite end of the bar growing faster. He also showed that angular correction of deformities of less than 20% usually corrected once the bar had been excised and if growth resumed. Bars of more than 50% of the physeal surface however did poorly with excision. He therefore does not excise physeal bars greater than 50%.

This initial enthusiasm was tempered by subsequent reports. So much so, that an earlier edition of Lovell and Winter's *Pediatric Orthopaedics* textbook (1990)²⁹ had a full chapter on partial growth plate arrest and its treatment. In the most recent edition, Lovell and Winter's *Pediatric Orthopaedics* (2006)³², it is limited to only three pages in the chapter on growth plate fractures. Williamson and Staheli (1990)²⁶ who, although they had good results of 82%, reported poor results for any physeal bar that exceeded 30% of the growth plate.

Birch (1992)³¹ then reported only a 33% success rate in 34 patients and 36 excised physeal bars. Even though he had some excellent results, most were unpredictable

and he described the procedure as “neither a very easy nor successful one”. This was echoed by Hasler and Foster (2002)³² who had a 40% success rate.

Unpredictable results for physeal bar resection following distal femoral physeal fractures, makes completion of the epiphysiodesis and contralateral epiphysiodesis a better option in adolescent patients.

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This Study

Aim

To assess whether physeal bar resection is a worthwhile procedure and if it still has a role in paediatric orthopaedic practice, we retrospectively reviewed 21 growth plate resections in 19 patients performed over a 17 year period (1987-2003).

Patients and Methods

Two of the 19 patients had bilateral sites (one of these patients had a dysplasia and the other had meningococcal septicaemia). The average age was 8,3 years (range 3 to 12 years).

Aetiology and sites

Table I shows the aetiology, site and size of the 21 physeal bars and the results of the physeal bar excisions. The most common cause was growth plate fractures (8), of which 5 were at the distal femur. The second commonest cause (5) was growth plate arrest due to meningococcal septicaemia. The commonest site was the distal femur (12), followed by the proximal tibia (5) and the distal tibia (4).

Table I

Aetiology, sites, size and results of 21 physeal bar resections

Aetiology	N = 21	Site	Salter Harris type	Size	Follow-up (m = maturity)	Result
Growth plate fracture	8	Distal femur = 5	I	20%	2 yrs	Excellent
			II	30%	-	Poor
			II	30%	m	Good
			III	30%	-	Poor
			IV	50%	-	Poor
		Proximal tibia = 1 Distal tibia = 2	II	15%	2 yrs	Excellent
			IV	30%	m	Good
			IV	20%	m	Excellent
Meningococcal septicaemia	5	Distal femur = 1		40%	-	Poor
		Proximal tibia = 3		40%	-	Poor
				30%	3 yrs	Good
				20%	3 yrs	Good
		Distal tibia = 1		20%	m	Excellent
Osteitis	3	Distal femur = 2 (neonatal)		15%	m	Good
				30%	m	Excellent
		Distal tibia = 1		20%	m	Excellent
Dysplasia	3	Distal femur = 2		25%	m	Good
				25%	m	Good
		Proximal tibia = 1 (Blount's)		25%	m	Good
Gunshot	1	Distal femur		20%	m	Excellent
Idiopathic	1	Distal femur		20%	4yrs	Excellent

Evaluation of the physeal bar

The physeal bar was evaluated for location and size, initially by biplanar tomography (8) (figure 13), subsequently biplanar tomography and MRI (8) and currently our preference is just MRI (5). Antero-posterior and lateral tomography and/or MRI was done and then a cross-sectional diagrammatic representation or map of the growth plate as described by Carlson and Wenger (1984)¹² (Figure 14).

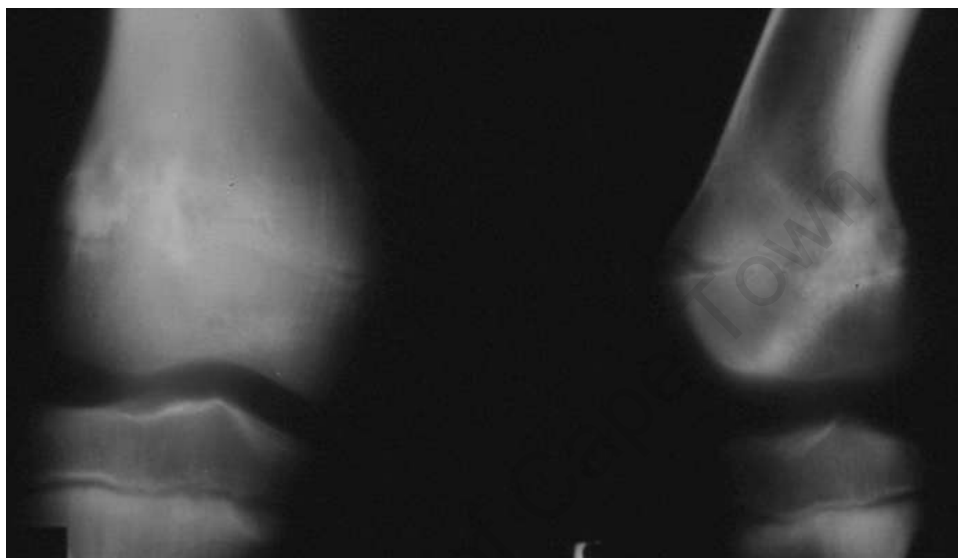


Figure 13 showing the tomograms of posterior lateral peripheral physeal bar

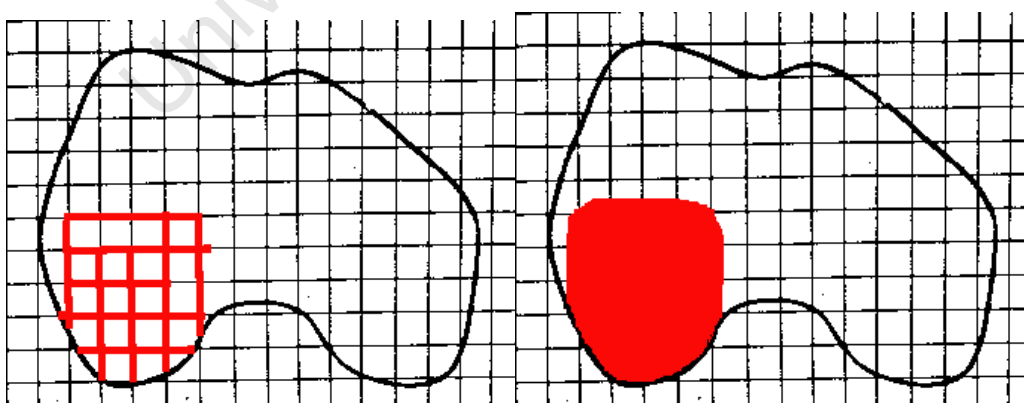


Figure 14 showing the above peripheral bar mapped as per the Carlson and Wenger technique

MRI was performed with a 1.5 Tesla magnet (Siemens, Symphony). The sequences done were T1 (TR 512, TE 13) and Gradient Rephased Echo (GRE) (TR 905, TE 26) in coronal and sagittal planes, perpendicular to the growth plate. The slice thickness used was 3mm and field of view 200mm.

The T1 sequence shows the physis (cartilage) as low signal intensity against the high signal intensity marrow (Figures 16b-18b,19a) and the GRE shows the physis as high signal intensity against the low signal intensity marrow and even lower signal intensity bone (Figure 5).

The average size of the physeal bars was 25% (range 15% to 50%). Only 3 physeal bars exceeded 30% in size.

The majority of the physeal bars were peripheral (15), one was central (meningococcal septicaemia) and five linear (two neonatal osteitis, two Salter Harris type IV growth plate fractures and one idiopathic).

Technique

All the physeal bar excisions were done in an operating theatre under tourniquet. An initial dose of a broad antibiotic (cefoxitin 25mg/kg) was given just before the start of the operation and before the tourniquet was inflated. An image intensifier was used to aid in location of the bar and to ensure its complete removal. No magnification, in the form of loupes or an operating microscope, was used. An extra light source was used in the form of a flexible surgical light, in order to be able to look into the cavity. A dental mirror was initially used but found to add little benefit.

Each bar was surgically approached on an individual basis with the peripheral bars (15) being approached directly from the side of the growth plate that they were on. The periosteum overlying the bar was excised in all cases to prevent reformation of the physeal bar. The linear bars (5) were all approached depending on which part of the physis they affected and this was mainly a direct approach from the periphery. They all require careful evaluation especially regarding their location. These patients were all positioned supine with a sand bag under the relevant side, in order to ensure good access to the surgical site. The 1 central bar was approached via a metaphyseal cortical window. This was a distal femoral physeal bar and a posterior approach to the physis was used. This patient was positioned in a prone position.

The normal physis was defined at the periphery of the bar, and the bar was then removed using a burr and/or gouge until normal physis was visible circumferentially (Pictures 8-10). Care was taken to ensure that as little normal physis as possible was removed. In the first 5 cases we used fat as interposition material, but subsequently we used cranioplast as it is more haemostatic and strengthens the defect. The patient also does not need to be protected post operatively with a Plaster of Paris cast and can weight bear.

The defect and interposition material was contoured as a collar button into the epiphysis in order to try and keep the interposition material in the epiphysis (Figures 11,15). In no cases was the cranioplast k-wired into the epiphysis. In only one case however did the cranioplast actually remain in the epiphysis.

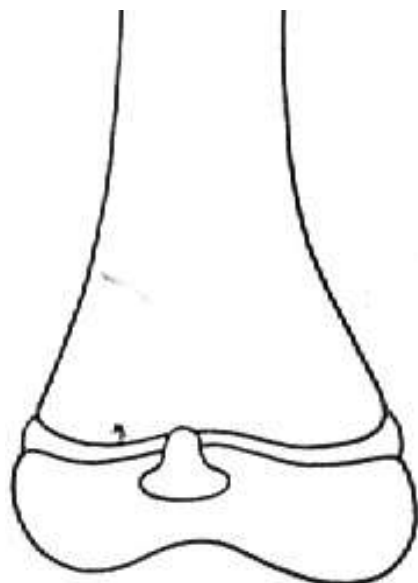


Figure 15:

Contouring the interposition material into the epiphysis as a collar button

Parallel Kirschner wires were then inserted as metal markers into the epiphysis and metaphysis in order to measure linear and angular growth (Figs 16-19).

A concomitant osteotomy was then done if the angular deformity was greater than 20° . This was done through the same incision in the metaphyseal bone and was either a barrel vault osteotomy in the tibia or a chevron osteotomy in the femur.

Follow-up

Five (24%) physal bar excisions failed to resume growth. They subsequently had completion of the epiphysiodesis and leg lengthening was then done. In the contralateral leg an epiphysiodesis was done, depending on the age of the child.

The remaining 16 physal bar excisions were followed up between 2 to 8 years, 11 to maturity. At follow-up the leg lengths were assessed clinically with a tape measure and whilst standing on blocks. An anteroposterior and lateral radiograph of the femur or tibia with a similar distance (100 cms) between the plate and the tube as on the immediate postoperative view was done. The increase in distance between the metal markers and the correction of the angular deformity was measured. A good result implied normal growth i.e. 10mm per year for the distal femur, 6mm for the proximal tibia and 4mm for the distal tibia. In an excellent result the growth achieved exceeded the expected growth.

Results

There were 8 (38%) excellent results (6 followed up to maturity) (Figs 16-20), where growth exceeded the expected normal growth, and 8 (38%) good results (5 followed up to maturity), where normal growth resumed. Of the 11 patients followed to maturity there was no leg length discrepancy that exceeded 1cm.

The 5 growth plate excisions that did not resume growth, failed from the start. Up to now there have been no premature arrests. These five failures occurred in the most commonly seen aetiologies. Three of the five due to distal femoral growth plate fractures failed; two were 30% and one was 50% in size. Two of the five due to meningococcal septicaemia failed; both were 40% in size.



Figure 16a: Anteroposterior radiograph of a 6-year-old girl with a posteromedial physeal bar of the distal tibial growth plate of the left ankle following meningococcal septicaemia

Figure 16b: T1 coronal MRI shows a peripheral bar (20% area)

Figure 16c: Immediate post operative view

Figure 16d: At maturity, growth of 42mm over 7 years was achieved (150% of expected)



Figure 17a: Anteroposterior radiograph of a 10-year-old girl with a physeal bar following a Salter Harris IV fracture of the medial malleolus of the left ankle

Figure 17b: T1 coronal MRI shows a linear, sclerotic bony bar (20% area)

Figure 17c: Immediate post operative view

Figure 17d: At maturity, growth of 18mm over 4 years was achieved (112% of expected)



Figure 18a: Anteroposterior radiograph of a 3-year-old girl with an idiopathic physeal bar of the right distal femoral growth plate

Figure 18b: T1 coronal MRI shows a sclerotic central bar (20%)

Figure 18c: Immediate post operative view

Figure 18d: At 4 year follow-up, growth of 60mm was achieved (150% of expected)



Figure 19a: T1 coronal MRI of a 5-year-old boy with a peripheral bar of the left lateral distal femoral growth plate following a gunshot

Figure 19b: Immediate post operative view showing a 20° valgus deformity

Figure 19c: At 6 year follow up, growth of 70mm was achieved (116% of expected), but angulation was uncorrected

Only 5 physeal bar excisions could be assessed for correction of angular deformities. This excluded two linear bars that were situated in the middle of the joint and had no angular deformity, the 5 failures, 6 who had concomitant osteotomies and three with too short a follow-up of only two to three years.

The remaining 5 physeal bar excisions corrected angular deformities of 0° to 20° over a period of 4 to 6 years. Angular correction was therefore not predictable, although figure 20 shows a correction of 20° over 6 years.



Figure 20a: Post operative anteroposterior radiograph of a 10-year-old boy with a peripheral bar of the left distal tibial plate following osteitis, showing a 20° varus deformity

Figure 20b: At maturity, growth of 37mm over 6 years (150% of expected) and angular correction of 20° was achieved

Discussion

This study shows 76% good and excellent results, which increases to 89% if physeal bars larger than 30% are excluded. We therefore do not share the current pessimism towards physeal bar resection for partial growth plate arrest^{33,35}. We feel that resection of a physeal bar $\leq 30\%$ in the young child with more than 5 years of growth remaining, is a worthwhile procedure and warrants a place in paediatric orthopaedics.

The five failures occurred in the commonest aetiologies, i.e. distal femoral growth plate fractures and meningococcal septicaemia.

Distal femoral growth plate fractures are notorious for physeal arrest because of the undulating nature of the growth plate which results in damage at the time of injury^{36,37}. The high incidence of failure following physeal bar resection in these patients is most likely due to secondary tethers which are present at an area separate from the physeal bar^{34,38}. This small secondary tether may not always be visible on plain radiographs, but can be seen on MRI (Figure 21).



Figure 21:

T1 coronal MRI of an 11-year-old boy with a lateral physeal bar following a Salter Harris II fracture of the right distal femoral growth plate. Note the small secondary tether in the medial Thurston Holland fragment

We agree that in the adolescent patient with physeal arrest due to distal femoral growth plate fractures, completion of the arrest with epiphysiodesis is a more predictable option. Since 1998 we have applied this policy in 5 patients with concomitant epiphysiodesis of the contralateral leg.

In meningococcal septicaemia, which occurs in much younger patients, the growth plate is damaged by ischaemia (vasculitis and disseminated intravascular coagulation) and the inflammatory response (osteitis) of the surrounding bone³⁹. Damage to the growth plate may manifest as partial growth plate arrest (Figure 16), or premature physeal closure (probably due to relative avascularity of the physis). The high failure rate in physeal bar resection in meningococcal septicaemia is most likely due to two factors: secondary tethers, similar to distal femoral growth plate fractures, which may not always be clearly visible on plain radiographs, but may be seen on MRI (Figure 5), or unpredictable premature physeal closure.

Three of the failures had physeal bars > 30%. This may have been a contributing factor, but Peterson (1990)²⁹ reported good results in bars constituting up to 50% of the growth plate. Physeal bars greater than 50% do poorly as the remaining normal physis seems unable to grow inward across the defect and allow satisfactory growth to resume. Since Williamson and Staheli (1990)²⁶ reported poor results in bars greater than 30%, we do not attempt to excise bars greater than 30%. This is controversial in the young patient with many years of growth left. In these young children, excision of bars greater than 50% may be attempted as the limb length discrepancy at maturity would be marked. If it fails, all other treatment strategies are still an option.

We found good correlation between the size and location of the bar at surgery and the map drawn pre-operatively from biplanar tomography and MRI. We currently prefer MRI. MRI has no radiation and elegantly demonstrates excellent tissue contrast as well as allowing multiplanar imaging without changing the position of the patient. Any interruption of the physis whether by a bony or cartilaginous bar or any interruption measuring just a few millimetres affecting the viability of the physis can be well seen on MRI⁴⁰. We have no experience with 3D MRI reconstruction^{15,16} or helical CT¹³.

At surgery it is important to ensure that normal physis is visible circumferentially and that there are no residual tethers. We attempted to contour the defect as a collar button into the epiphysis in all our patients (Figure 15). In all the patients however, except the patient shown in figure 18, the defect stayed in the metaphysis. This did not influence the result.

Only 5 physeal bar resections could be assessed for angular correction. Angular correction was not as predictable as reported by Peterson (1990)²⁹ and ranged from 0 to 20° over 4 to 6 years. Our current policy is to do a concomitant osteotomy if the angulation exceeds 20°. If the angulation is $\leq 20^\circ$ we will await possible correction and perform an osteotomy at maturity if required. Growth plate fractures are followed up at 3 and 6 months post injury, to try and diagnose growth disturbance early before deformity occurs. A growth arrest or Harris line that is oblique (not parallel to the physis) or has a focal defect suggests early physeal arrest⁷. The physeal bar can then be confirmed with MRI⁴⁰.

We therefore conclude that physeal bar resection for partial growth plate arrest in the younger patient is a worthwhile procedure if the bar does not exceed 30% of the size of the physis and more than 2 years of skeletal growth remains. In physeal bars due to distal femoral growth plate fractures and meningococcal septicaemia, the prognosis is guarded.

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Acknowledgements

Firstly I would like to thank my wife, Robyn, for her patience during the 3 years whilst this dissertation has been under progress. The many times that it has been hauled out to work on and put away again. Without her encouragement I would never have completed it. I would also like to extend my gratitude to my supervisor, Professor EB Hoffman, who helped me with the study and the work done back in 2005/6. It was his idea to do my MMed on this topic. I would also like to thank Dr S Dix-Peek for being my proof reader and his input. Lastly to the Department of Orthopaedics at the University of Cape Town for their encouragement and continued wish to complete the dissertation, I extend my gratitude.